NASA COST ESTIMATING SYMPOSIUM

NASA Space Operations Cost Model (SOCM)

INTRODUCTION AND SCHEDULE

DEVELOPMENT STATUS AND PLANS

INTEGRATION TO SUPPORT LIFE CYCLE ANALYSES

Mark Jacobs, SAIC

Jet Propulsion Laboratory
Pasadena, CA

March 1-3, 2000

Science Applications International Corporation
An Employee-Owned Company

Space Operations Cost Model (SOCM)
Introduction

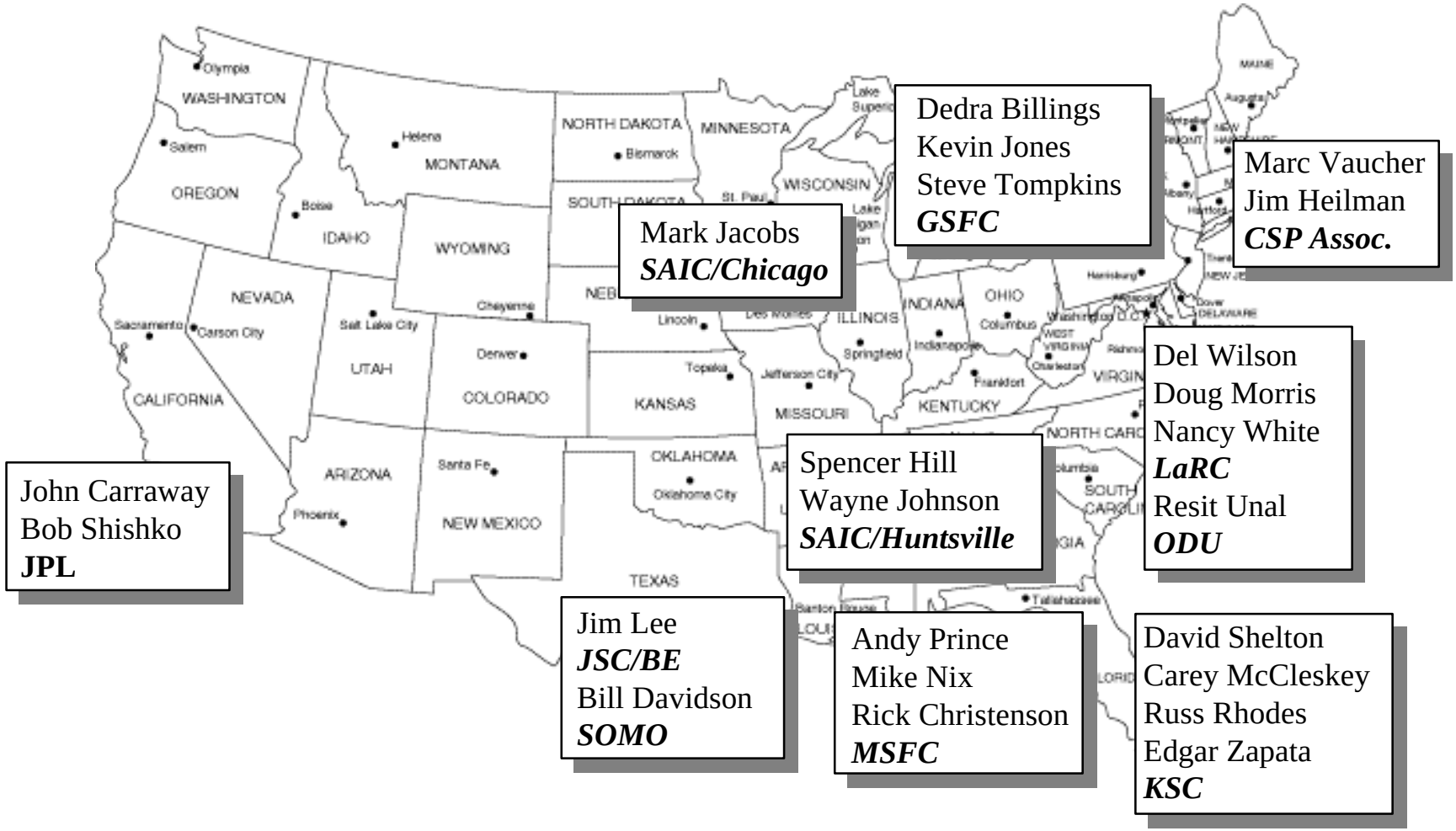
- Study objective is to develop a suite of tools to estimate space mission operations costs for future NASA projects

  - Emphasis on assessments of advanced technology impacts
  - Includes modules for ***Planetary*** and ***Earth Orbiting*** robotic science missions, orbiting ***Space Facilities***,***Launch/Transportation Systems***, and ***Lunar/Mars Exploration*** *(Human Spaceflight)*
  - Estimating methodologies utilize a combination of parametric equations based on collected data and constructive relationships capturing expert judgement
  - Rapid prototyping methods are used to facilitate testing/validation and maximize user interaction/feedback

- Study team includes cost/technical/programmatic experts from each Center

- Missions under consideration span a broad range of project types

NASA Space Operations Cost Model Study Team

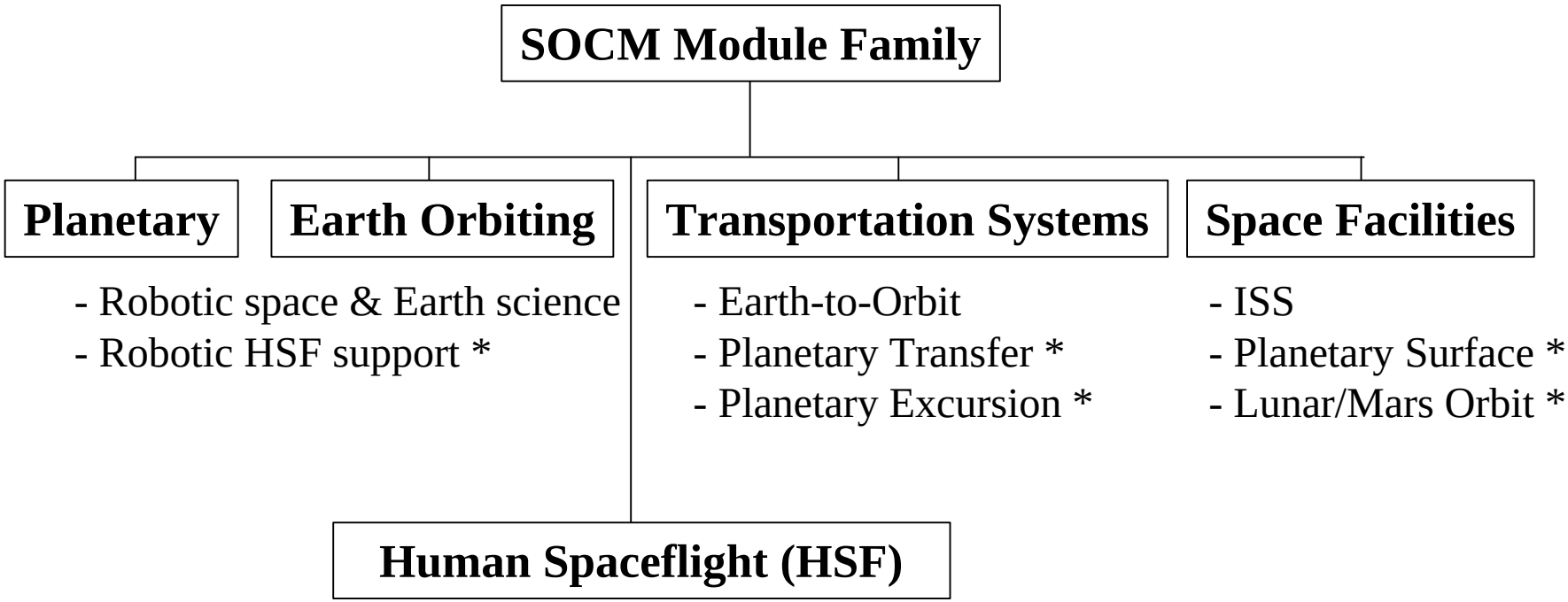


Science Applications International Corporation

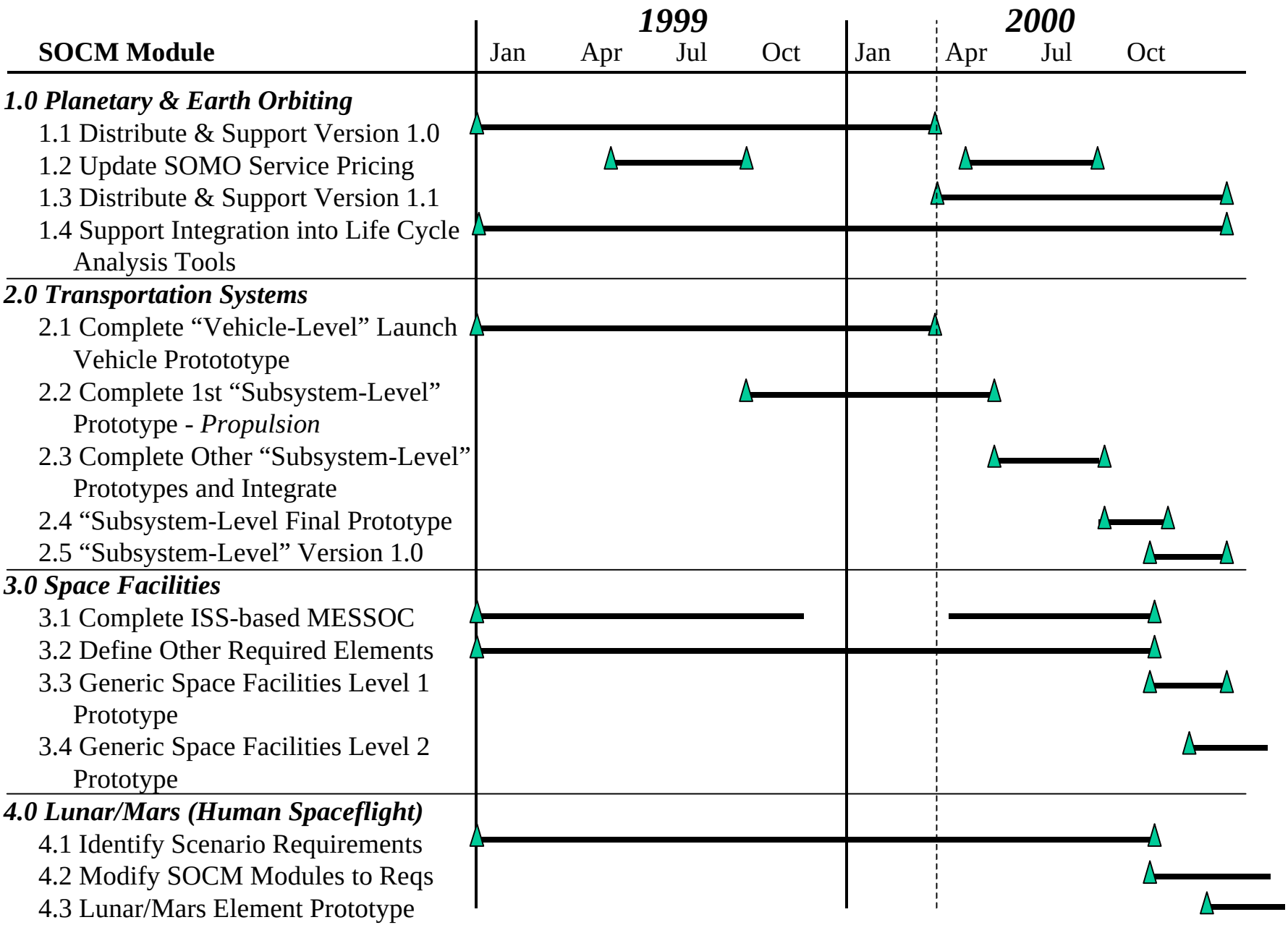
NASA Space Operations Cost Model (SOCM) Rapid Prototype Reference Mission Set

NASA Center	Conventional Approach (past projects)	Use of Low Cost Modern Business Practices (current projects/SOP)	Future Missions (future projects/SOA)
Goddard Space Flight Center (GSFC)	Gamma Ray Observatory (GRO) Hubble Space Telescope (HST) Energetic UV Explorer (EUVE)	Advanced Composition Explorer (ACE) Far UV Spectroscopic Explorer (FUSE) Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX) X-Ray Timing Explorer (XTE)	Midex (MAP, IMAGE) SMEX (TRACE, FAST, SWAS, WIRE) ESSP EOS NMP EO Missions
Marshall Space Flight Center (MSFC)		Advanced X-ray Astrophysics Facility (AXAF) Space Station	Lunar/Mars Exploration Advanced Launch Vehicles
Johnson Space Center (JSC)	Shuttle Orbiter	Space Station	Lunar/Mars Exploration
Jet Propulsion Laboratory (JPL)	Galileo Magellan Voyager	Discovery Program (Mars Pathfinder, NEAR/APL) Mars Global Surveyor (MGS)	New Millennium DS Missions Discovery Program (Lunar Prospector, Stardust) Pluto Flyby
Kennedy Space Center (KSC)	Shuttle Orbiter		HRST, RLV

Modules Included in SOCM Tool Set



SOCM Development Schedule



SOCM MODULE DEVELOPMENT RECENT IMPROVEMENTS
PLANETARY AND EARTH ORBITING MODULES

- **Improved Integration of Multiple Mission Phases**

- **Added Phase for "Post-Flight Data Analysis"**

- **Enhanced Handling of Operations Service Costs**
  - Shows SOMO service pricing next to SOCM estimate for comparison

- **Additional Testing and Validation**
  - Independent Cost Assessment Support for > 100 mission concepts

- **Pre-Processor File Facilitates Integration Into Other Tools**
  - Adds ability to link SOCM inputs to custom input format

LEVEL 1 SOCM INPUTS - EARTH ORBITING MISSIONS
TOP LEVEL REQUIREMENTS & IMPLEMENTATION STRATEGY

MISSION CHARACTERIZATION

- Mission Type
- Mission Target
- Mission Phase Durations

PROGRAMMATICS CHARACTERIZATION

- Mission Risk Class/ Risk Mitigation Plan
- Management Plan
- System Development Details

PAYLOAD CHARACTERIZATION

- Number and Type of Instruments
- Identification of Potential Conflicts
- Science Team Support

SPACECRAFT DESIGN CHARACTERIZATION

- High Level Description of Flight System Development
- Complexity/Attitude Attitude Control Type

GDS/MOS CHARACTERIZATION

- Operation Strategy
- Architecture Design
-Heritage

DEFINE ALL LEVEL 1 INPUTS

VIEW OUTPUT

WBS OPTIONS

ADJUST OPS SERVICES

LEVEL 2 INPUTS

Selected Cost Drivers:		Ops$ Range		Ops$ Range		Ops$ Range	units	Definitions
Mission Implementation		**Low**		**Medium**		**High**		
Engineering Event Complexity	○	Routine, Non-hazardous events	◉	Repetitive/No Hazardous Events	○	Risky events/Significant Real-Time Contact		Number of unique engrng cmd sequences
Operations Type	○	Survey	◉	Orbit-driven/Activities based on orbital events	○	Targeted and/or Constrained		High level characterization of operation concept
Science Event Complexity	○	Survey	◉	Few constraints	○	Constrained/Multiple observation modes		Number of unique science instrument command sequences
Programmatics Implementation		**Low**		**Medium**		**High**		
Staff Experience	○	More than 2 similar missions	◉	1 or 2 similar missions	○	New OPS team		Experience of ops staff with similar systems
Risk Plan - S/C	○	Small S/C, No redundancy, Tech demo mission	◉	Class C, $100M flt system development	○	Redundant S/C, several $100M development		Measure of the S/C operational risk based on design implementation
Risk Plan - Instruments/Payload	○	Simple payload, No redundancy	◉	Few hazardous OPS, Limited redundancy	○	Complex, redundant S/C		Measure of the instrument/payload operational risk based on design implementation
Risk Plan - GDS/MOS	○	Accept min risk to msn safety, and mod data loss	◉	Accept mod risk to efficiency and data loss < 5%	○	Accept min risk to efficiency and data loss < 1%		Measure of the GDS/MOS operational risk based on design implementation
Crosstraining/Staffing Overlaps	○	Fully crosstrained	◉	Crosstrained within functions	○	Limited crosstraining		Number of staff assigned/trained to perform same function
H/W Redundancy	○	Limited or no redundancy	◉	Selected redundancy	○	Full redundancy with rapid switchover		GDS/MOS system redundancy

LEVEL 2 MISSION OPERATIONS ESTIMATE - Phase E

Test Case - EO1

Costs are FY 2000

	Nominal	Extended	Post-Flight DA	TOTALS
Annual FTE/$ Estimates				
Flight Ops	11.0	5.5		
Nav/Tracking Ops	0.9	0.4		
Science Ops	21.4	10.7	16.1	
Total FTEs/yr	***33.3***	***16.6***	***16.1***	
Annual FTE Cost	***$5.1***	***$2.6***	***$2.5***	***$4.2***
Annual Ops Serv.				***$0.0***
Summary				
Phase duration (mo)	*36.0*	*12.0*	*6.0*	*54.0*
Total Ops Services				***$0.0***
Total FTE $M	***$15.3***	***$2.6***	***$1.3***	***$19.1***
Total $M				***$19.1***

LEVEL 2 MISSION OPERATIONS COST ESTIMATE	2000 *constant FY $K*			
Test Case - EO1	**Phase E** ***Nominal***	**Phase E** ***Extended***	***Post-Flight DA***	***Phase E*** **Total**
1.0 MISSION PLANNING & INTEGRATION	464.3	77.4		541.7
2.0 COMMAND/UPLINK MANAGEMENT	1070.6	178.4		1249.0
3.0 MISSION CONTROL & OPS	1196.2	199.4		1395.5
4.0 DATA CAPTURE	757.7	126.3		884.0
5.0 POS/LOC PLANNING & ANALYSIS	65.6	10.9		76.5
6.0 S/C PLANNING & ANALYSIS	149.0	24.8		173.8
7.0 SCI PLANNING & ANALYSIS	2424.5	404.1		2828.6
8.0 SCIENCE DATA PROCESSING	4498.2	749.7	749.7	5997.6
9.0 LONG-TERM ARCHIVES	1755.6	292.6	292.6	2340.8
10.0 SYSTEM ENGINEERING, INTEG, & TES	1319.9	220.0		1539.9
11.0 COMPUTER & COMM SUPPORT	619.9	103.3	103.3	826.5
12.0 SCIENCE INVESTIGATIONS	756.4	126.1	126.1	1008.5
13.0 MANAGEMENT	223.1	37.2		260.3
Project Direct Total	15,301.0	2,550.2	1,271.7	**19,122.8**

Operations Services **0.0**

Project TOTAL **19,122.8**

LEVEL 2 MISSION OPERATIONS COST ESTIMATE - Phase E TOTAL

2000

Test Case - EO1

constant FY $K

	a) S/C	b) Science	c) Grnd Sys	d) Nav Sys	TOTALS
I PLAN	235	1,205	305	112	**1,857**
II COMMAND	1,095	2,981	490	119	**4,686**
III MONITOR	376	616	251	31	**1,274**
IV ANALYZE	94	569	188	52	**903**
V DEVELOP					
VI DATA SERVICES	696	6,405	426	151	**7,678**
VII OVERHEAD SERVICES	869	1,532	861	90	**3,352**
Project Direct Total	**3,366**	**13,308**	**2,521**	**555**	**19,749**

Operations Services Cost **0.0**

Project TOTAL **19,749**

SOCM MODULE DEVELOPMENT NEEDS
PLANETARY AND EARTH ORBITING MODULES

- **Additional Testing and Validation**
  - Discovery Program
  - Explorers
  - Mars Exploration
  - Outer Planet Exploration

- **Enhanced Handling of Operations Service Costs**
  - Update SOMO service pricing
  - Methodology to estimate life cycle cost impacts from services

- **More Users**
  - JPL PDC
  - GSFC IMDC
  - Industry/Commercial applications
  - Training and Demonstrations

SOCM MODULE DEVELOPMENT NEEDS
SPACE FACILITIES MODULE

- **Complete ISS-based RPM**
  - Initial MESSOC update will serve as a SOCM “Level 2” model
  - More general “Level 1” and “Level 2” interfaces need to be developed

- **Testing and Validation**
  - ISS
  - Mars Design Reference Mission Surface Systems

- **More Users**
  - JSC ISS Office
  - JSC Mars Exploration Program
  - MSFC Mars Exploration Studies
  - Training and Demonstrations

SOCM MODULE DEVELOPMENT RECENT IMPROVEMENTS
LAUNCH SYSTEMS MODULE

- **Vehicle-Level "Proof-of-Concept" Prototype Complete**
  - Includes integration of RMAT Response Surface Model

- **Working with Subsystem Specialists to develop Subsystem-Level Prototypes**

- **Interfacing with Other Launch Vehicle Studies/Tools**
  - KSC Vision Spaceport and other architecture studies
  - MSFC Spaceliner 100
  - LaRC Reliability and Maintainability Analysis Tool (RMAT)

- **Implementing Tool Integration to Support Life Cycle Analysis**
  - Recent MSFC demonstration linked SOCM, NAFCOM, and numerous MSFC economic/market assessment models

SOCM Launch Systems Rapid Prototype Model 3b Summary Output

2/25/00

Concept Title: **MJs Test Run**

Launch System Operations Summary	Start-up	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
										FY for cost output ($M):	*1999*
Total Cost by Category											
Facilities	629	19	19	19	19	19	19	19	19	19	19
GSE	1,714	51	51	51	51	51	51	51	51	51	51
Spares	257	8	8	8	8	8	8	8	8	8	8
Labor	62	62	62	62	62	62	62	62	62	62	62
Variable	*53*	*53*	*53*	*53*	*53*	*53*	*53*	*53*	*53*	*53*	*53*
Fixed	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*	*9*
Propellants & Fluids	2	1	1	1	1	1	1	1	1	1	1
Total Annual Cost	**2,665**	**142**	**142**	**142**	**142**	**142**	**142**	**142**	**142**	**142**	**142**
Cycle Times by Function											
(days/flight)											
Process	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Launch	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Flight Ops	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Land/Recover	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
Support Infrastructure	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total per Vehicle, days	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5
Capabilities											
Max Flights/Year	13	13	13	13	13	13	13	13	13	13	13
Planned Flights/Year	13	13	13	13	13	13	13	13	13	13	13
% Utilization	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Flights/Year/Vehicle	9	9	9	9	9	9	9	9	9	9	9
Minimum # of Vehicles	2	2	2	2	2	2	2	2	2	2	2

SOCM LAUNCH SYSTEMS RAPID PROTOTYPE MODEL 3b - PROCESSING Function

RMAT RSM Inputs	
Dry Weight, lbs	171,919
Length, ft	122
Height, ft	40
Wing Span, ft	78
Number of Engines	3
Mission Length, days	5
Wetted Area, ft^2	11,999
Fuselage Area, ft^2	6,636
Fuselage Volume, ft^3	27,900

Processing Cycle Time Inputs
Stack/Integration Time, days
2
Transport to Launch, days
0.5

RMAT RSM Outputs		
Mission Reliability	**0.9998990**	
Number of Maintenance Actions	**187**	
Work-Hours per Cycle - Total	**17,893**	
Scheduled work-hours		***3,065***
Unscheduled work-hours		***14,828***
Headcount	**1083**	

SOCM LAUNCH SYSTEMS RAPID PROTOTYPE MODEL 3b - PROCESSING Function

Vehicle-Level Inputs	Choice	1 SOA	2 25% improvement	3 50% improvement
Design Life (# of missions/vehicle)	**1**	100 or less	100 - 200	200 - 500
Maintenance Accessibilty	**1**	Most maintenance items require substantial effort to access	Few items directly accessible, other maintenance items difficult to access	Items likely to require maintenance are directly accessible, other maintenance items moderately difficult to access
Vehicle Health Monitoring	**1**	Automated health monitoring for only critical systems, substantial manual check-out on ground required	Some systems have automated health monitoring capability, substantial manual check-out on ground required	Most systems have automated health monitoring capability, moderate manual check-out on ground required
Thermal Protection System	**1**	Complex ceramic tile design, each tile geometry unique	Improved ceramic tile design; minimal coating, waterproofing, purge required	Improved ceramic tile design; no coating, waterproofing, purge required
Use of COTS	**1**	Many components with low technology maturity	STS-type components	Mix of STS and COTS components with demonstrated high reliability
Fuel Commonality (primary propulson & RCS)	**1**	Multi-stage with more than 2 fluids + other fluid system functions (e.g., active cooling)	Multi-stage with 2 fluids + other fluid system functions (e.g., active cooling)	Single stage with 2 fluids + other fluid system functions (e.g., active cooling)
Environmental Hazards	**1**	Toxic fluids required for flight and ground operations	Few toxic fluids for flight; some toxics used for manufacture, assembly, and cleaning	No toxic fluids for flight; few toxics used for manufacture, assembly, and cleaning
Structural Safety Factor	**1**	< 1.3	1.3 - 1.5	1.5 - 1.7
Propellant Operating Max Pressure (psi)	**1**	> 3,500	2,500 - 3,500	1,500 - 2,500
Ascent Power Level (% of max)	**1**	Greater than 105%	100 - 105%	95 - 100%

SOCM MODULE DEVELOPMENT NEEDS
LAUNCH SYSTEMS MODULE

- **Complete "Subsystem-Level" RPMs**
  - Work in progress with MSFC, LaRC, and KSC expert support
  - Similar format to Vehicle-Level prototype

- **Testing and Validation**
  - STS
  - RLV concepts

- **Derive methodologies to apply to other space transportation systems**

- **Integration into Life Cycle Analysis Simulations/Tools**

- **More Users**
  - MSFC, KSC, and other government-sponsored study teams
  - Industry/Commercial applications
  - Training and Demonstrations

SOCM MODULE DEVELOPMENT NEEDS
HUMAN SPACEFLIGHT (LUNAR/MARS) MODULE

- **Develop Estimating Methodology Plan**
  - HSF-specific inputs
  - HSF Mission Scenario Definition - Mars DRMs

- **Identify HSF-specific requirements and enhancements for each existing SOCM module**

- **Derive Reduced Input Set to Run SOCM Modules with HSF Input Data**

- **More Users**
  - JSC Mars Exploration Office
  - MSFC Mars Exploration Studies
  - Training and Demonstrations

Space Operations Cost Model (SOCM)
Elements Required to Support Lunar/Mars Exploration
Life Cycle Analyses

Planetary and Earth Orbiting SOCM Module

- ***Robotic Science***
  - explorers
  - orbiters
  - landers
  - probes
  - other

Space Facilities SOCM Module

- ***Orbiting Facilities***
  - Laboratories
  - Depots
  - On-Orbit Assembly and/or Transfer Node
- ***Surface Systems***
  - Labs/Habs
  - ISRU
  - Power Systems

Transportation Systems SOCM Module

- ***Launch Vehicles***
  - RLV/ELV
- ***Interplanetary Transfer***
  - LTV/MTV
- ***Excursion***
  - LEV/MEV
- ***Surface Launch/Land Facilities***

Space Operations Cost Model (SOCM)
Life Cycle Analysis Support Concept Alternatives

1) Add SOCM/Ops Model input/outputs to an existing model or interface

- Can be done with total SOCM input/output set or at a high-level
- Easiest option to implement

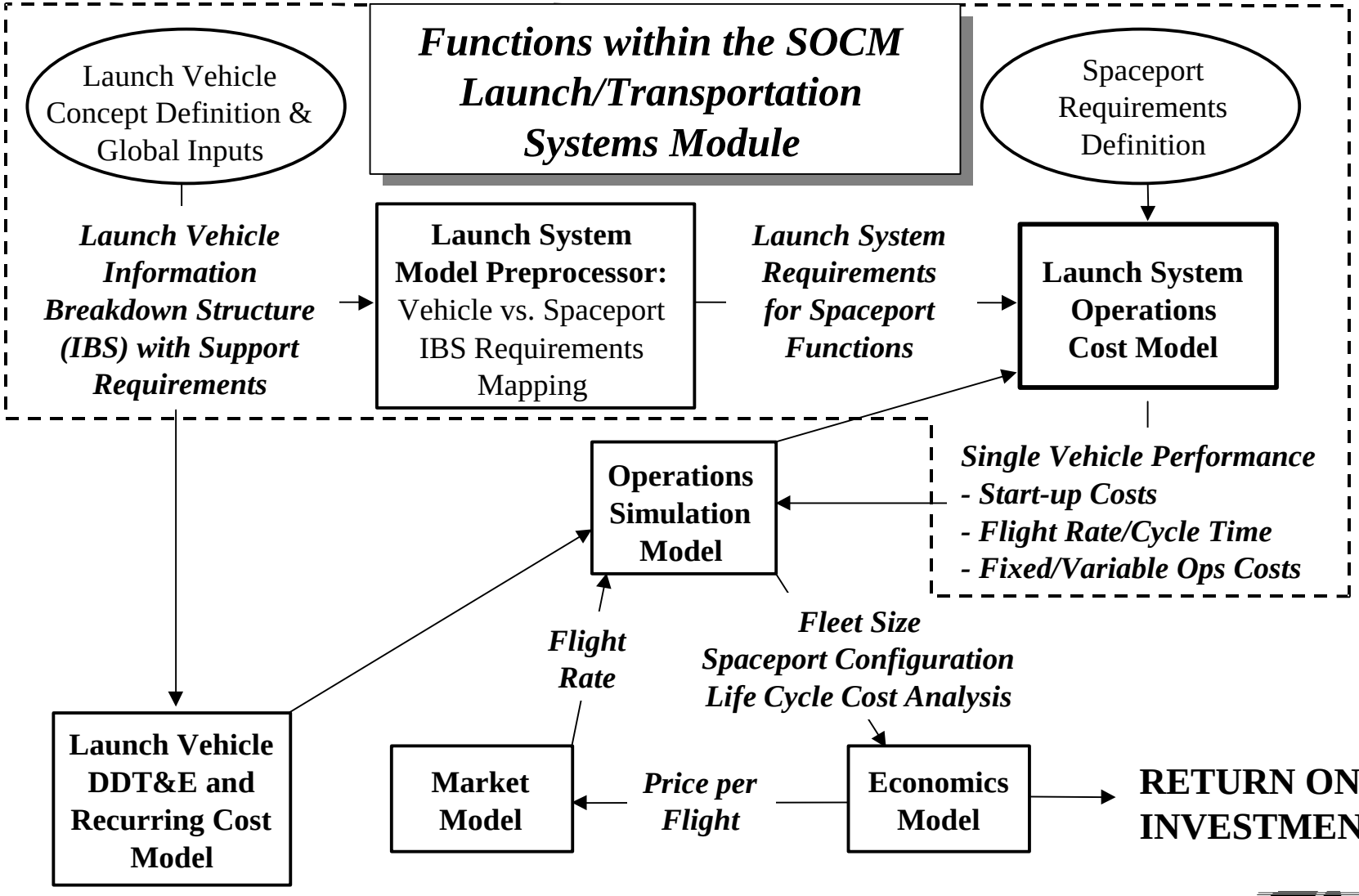
2) Fully integrate SOCM/Ops Model into a specific development model(s)

- May require incorporating SOCM operations cost estimating capabilities into a new programming environment
- Approach used in JPL PDC (Team X)

3) Develop Generic Life Cycle Assessment Input Forms

- Forms could be developed independent of model data requirements focusing on key data that is typically known
- Development and Operations modelers would need to develop an interface to map the generic form data into their model inputs and output their model results to the generic form
- Most difficult option to implement but enables comparisons of assessment results from different user-selected models

SOCM Launch/ Transportation Systems Module
Integration into a Life Cycle Analysis/Simulation Tool



Science Applications International Corporation

Launch System Life Cycle Analysis Rapid Prototype Example

INPUTS AND SELECTED SUMMARY OUTPUTS

Development	Operations	Economics				
Vehicle Name	*Ops Scenario*	*Govt Guaranteed Loan*	*Cost Share %*	*ISS PPF*	*Commercial PPF*	*Emerging Market PPF*
Commercial Best Practices with Adv Dev	**25% Improvement**	**Yes**	**50%**	**$300**	**$50**	**$50**
Old Ways	SOA	Yes	Enter value	$M/flight	$M/flight	$M/flight
Govt Managed Advanced Dev	25% Improvement	No				
Commercial Best Practices no Adv Dev	50% Improvement					
Commercial Best Practices with Adv Dev	75% Improvement					
Commercial with Adv Dev and Full Scale Prototype Funded by Govt	Low Cost Operations Goal					

Total Project IRR =	***26%***
Average Annual Cost per Flight =	***$53***
Total Dev Cost through 1st Unit =	***$9,252***

ECONOMIC MODEL OUTPUT SUMMARY

Price Per Pound to LEO	$3,215	*$/lb, average over all customers*
LCC to NASA, $B	$82.5	*B, discounted @ 7% real*
Near-Term NASA Investment	$14.0	*B, undiscounted*
Total Project IRR	26%	
Before-Tax ROE	44%	
After-Tax Equity NPV	$2.7	*B, discounted @ 15% real*

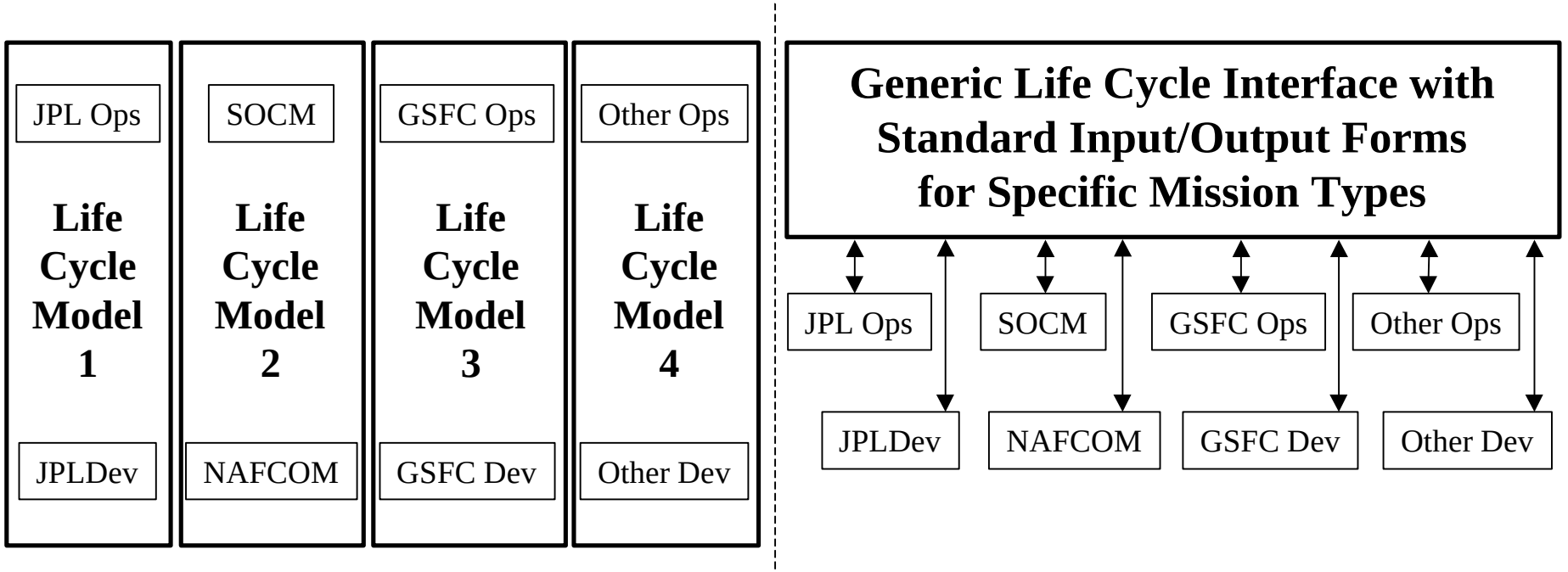
OPERATIONS MODEL OUTPUT

Operations Facility Startup Costs	$4,505	*M*
Average Annual Operations Costs (last 5 years)	$1,945	*M*
Average Annual Flight Rate	37	
Average Annual Cost per Flight	$53	*M/flight*

DEVELOPMENT MODEL OUTPUT

	Adv Dev	*DDT&E*	*Flight Unit*	*Total*	
Advanced Technology Development	$ 5,000			***$ 5,000***	
Vehicle Subsystems (less Engines)		$ 1,571	$ 463	***$ 2,034***	
Engines		$ 1,190	$ 274	***$ 1,465***	
System Integration		$ 564	$ 189	***$ 753***	
TOTAL	**$ 5,000**	**$ 3,326**	**$ 926**	**$ 9,252**	**M**

Life Cycle Analysis Support Concept Alternatives
Integrated Development & Ops vs. Generic Interface



- Life Cycle Models integrating specific development and operations models exist (JPL PDC/Team X and others), but tend to be tailored to specific mission types and organization/programmatic requirements
- Development of a Generic Interface capable of input/output to a variety of development and operations tools may be more complicated to implement, but would provide results from a variety of perspectives and enhance flexibility

Space Operations Cost Model (SOCM)
LESSONS LEARNED

- Operations model development is substantially aided by early involvement of a diverse group of technical, programmatic, and cost experts.
- Incorporating feedback quickly into Rapid Prototype Models enables implementation of incremental improvements and facilitates testing of innovative methodologies.
- Rapidly advancing communications and computing technology necessitates periodic updating of many input values and revisiting current “tuning” settings against recent mission benchmarks (most SOCM modules use a mix of constructive relationships and parametrics based on collected data).
- There are many alternatives for integrating operations modeling with a life cycle analysis tool. All options would benefit from early coordination between model developers and implementation of the rapid prototyping technique to generate useful products quickly